MOKELUMNE WATERSHED AVOIDED COST ANALYSIS:

Why Sierra Fuel Treatments Make Economic Sense

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Appendix D: Debris Flow Modeling

D.1 Introduction

Debris flows can be one of the most dangerous consequences of rainfall on steep terrain recently burned by wildfire. The probability of a post-fire debris flow occurring is low as most burned watersheds will produce sediment laden flows (as discussed in Appendix C) in response to heavy precipitation; however basins that are prone to debris flows warrant special attention due to the extreme risk they pose to life and property (Cannon et al. 2010). In order to gauge the impact the modeled fuel reduction treatments would have on debris flows in the basin, we modeled the probabilities and potential volumes of post-fire debris flows before and after fuel reduction treatments. Modeling was carried out using empirical models developed by the United States Geological Survey (USGS) to assess post-fire debris flow threats in the intermountain west (Cannon et al. 2010). We predicted a 12% decline in potential post-fire debris flow volume and a 27% reduction in debris flow probability in the portions of the watershed with modeled treatments. The predictions of potential post-fire debris flow volumes ranged from 0 to 640,000 m^3. Our predictions were well within the range of the field observations of debris flow volumes from 55 recently burned basins. These basins burned in 8 different fires in Colorado, California and Utah and measured debris flow volumes ranged from 174 to 864,300 m^3 (Cannon et al. 2010).

D.2 Modeling approach

A GIS tool was created to apply two empirical models to small sub-basins over large spatial areas. These models were generated from datasets gathered from 388 basins that burned in 15 different fires in the intermountain western US states (Cannon et al. 2010). The first equation used slope, burn area, and total storm precipitation to estimate mean volume (V, in m^3) of material deposited by a debris flow (Cannon et al. 2010). Equation 2 predicts the probability that a debris flow will occur (P) in a given basin (Cannon et al. 2010). Model inputs included a Digital Elevation Model (DEM) to determine slope and roughness, a delineation of sub-basins, storm intensity and total rainfall, clay percentage and liquid limit of soils, and a burn severity map. Storm intensities and total rainfall were derived from a series of spatial NOAA design storms. DEM and soil parameters were derived from the National Map and from STATSGO. The FlamMap derived burn severity maps (Appendix A) were used to represent post-fire conditions for before (current conditions) and after fuel reduction treatments. Modeling results from the debris flow probability run for current conditions could serve as a post-fire debris flow hazard risk map. The models are as follows:

$$\mathrm{V} = \exp(7.2 + 0.6 * lnA + 0.7 * \sqrt{B} + 0.2 * \sqrt{T} + 0.3) \qquad \text{(Eq 1)}$$

Where A represents the area (km^2) of the sub-basin with slopes that are greater than or equal to 30%, B represents area (km^2) of the sub-basin burned at moderate or high severity, and T represents the total storm rainfall (mm).

$$\mathrm{P} = \frac{\exp(-0.7 + 0.03 * \%A - 1.6 * R + 0.06 * \%B + 0.07 * I + 0.2 * C - 0.4 * LL)}{1 + \exp(-0.7 + 0.03 * \%A - 1.6 * R + 0.06 * \%B + 0.07 * I + 0.2 * C - 0.4 * LL)} \qquad \text{(Eq 2)}$$

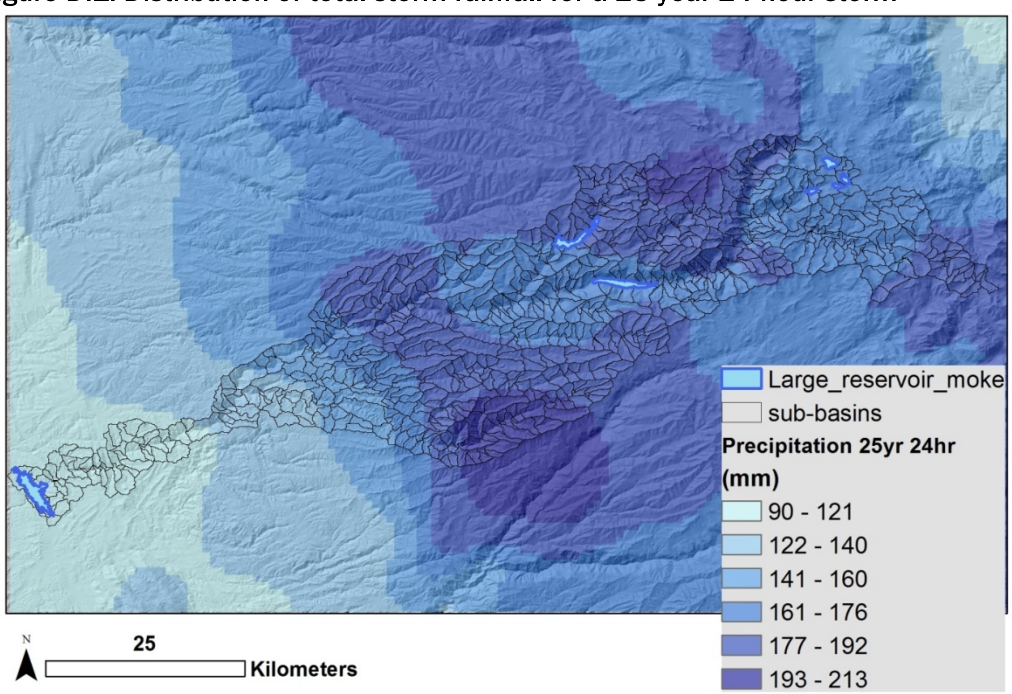
For predicting probability of debris flow occurrence, %A represents the percentage of the sub-basin with slopes greater than or equal to 30%, R represents sub-basin ruggedness – change in elevation divided by square root of the area (Gartner et al. 2008), %B represents the percentage of area burned at moderate or high severity, and I represents average storm rainfall intensity (mm/hour). The two soil parameters are C, the percentage of clay content in the soil, and LL, the liquid limit. Liquid limit is a measure of the moisture content required to change soil behavior from plastic to liquid.

The two empirical models (Eq 1 and 2) were applied spatially using a watershed delineation that contained 776 sub-basins. The smaller scale delineation was needed in order to ensure the areas of each sub-basin were not larger than the basins used in generating the empirical models, thus ensuring that the models were applied in a manner consistent with how they were designed to operate.

D.2.1 Climate data

The Debris Flow model uses storm data rather than the daily weather parameters used by the WEPP model. Gridded NOAA precipitation frequency estimates for California (http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html) were used to generate storm intensity and total precipitation. The grids are available for a variety of storms ranging in duration from five minutes through 60 days and for storm return intervals from 1 to 1,000 years (Bonnin 2004). The grids contain total storm precipitation; therefore in order to obtain storm intensity we divided the total rainfall by the storm duration. Zonal statistical tools were used to obtain the average rainfall for each sub-basin. We modeled five storms with a variety of return intervals and duration periods in order to capture storms with high intensities (shorter duration) and storms with high total rainfall (Figure D.1 displays one of the five storms).

Figure D.1: Distribution of total storm rainfall for a 25 year 24 hour storm



D.2.2 Land cover and plant/management input files for Debris Flow modeling

For the Debris Flow model, the only landcover inputs needed were the FlamMap results (derived burn severity maps, see Appendix A) for before and after fuel treatments. Our GIS tool used zonal statistics to calculate the area of each sub-basin predicted to burn at moderate and high severity. This input was the only variable to change between the two sets of model runs.

D.2.3 Soils data

The soil parameters needed for the Debris Flow modeling included the percentage of clay in the soils and the liquid limit of the soil. These parameters were obtained directly from the STATSGO2 dataset (Soil Survey Staff 2013) using the Natural Resource Conservation Service Soil Data Viewer to obtain maps of both parameters. These parameters could vary spatially across the sub-basin, so they were also averaged using zonal statistics.

D.2.4 Topographic data, watershed delineation, and processing

Our DEM was downloaded from the National Elevation Dataset at a 30m resolution (Gesch et al., 2002; Gesch, 2007). The DEM was used to create our watershed delineation and derive the required slope input using ESRI ArcGIS tools. Surface roughness was also derived from the DEM using zonal statistics to find the maximum and minimum elevation in each sub-basin.

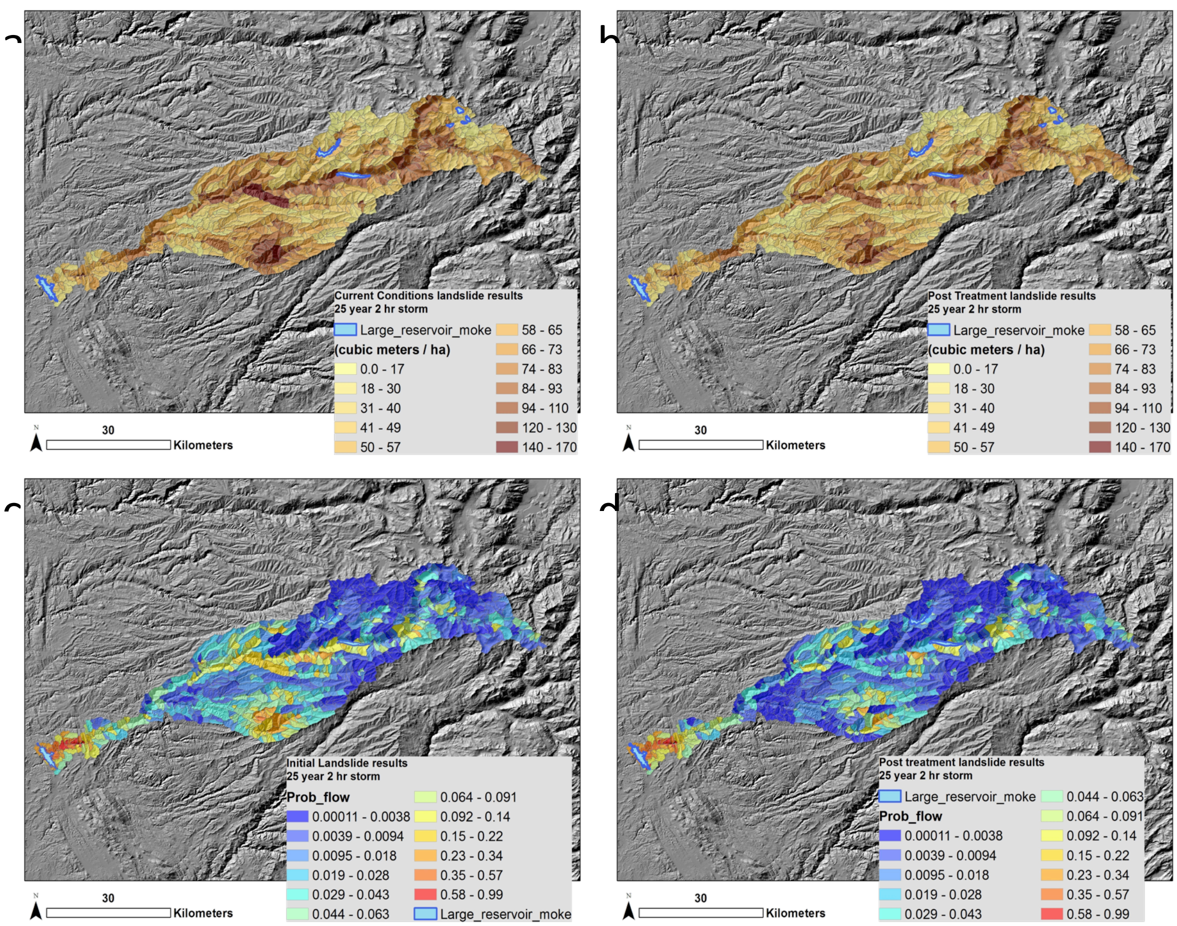
D.3 Results

We modeled five different storms in order to obtain a range of parameter values for total storm precipitation and intensity (Table D.1). Storm intensities for longer duration storms were low as they represented average intensities over the entire storm. To obtain higher intensity values in the basin, we modeled a shorter one-hour storm. Longer duration storms could easily have periods of high rainfall intensity, which would not be represented by an averaged intensity value. The longer duration storms generated higher total precipitation amounts and therefore higher predicted debris flow volumes. Shorter duration storms generated higher storm intensity values and hence higher probabilities of debris flow occurrence, but with smaller predicted volumes than longer duration storms (Table D.1). The probability of a post-fire debris flow event in an individual sub-basin is low, generally less than 1% (Table D.1, Figure D.2). However, if the entire watershed were to burn, the likelihood of a debris flow event occurring within the watershed would increase dramatically as there are several hundred sub-basins. For each sub-basin, we predicted debris flow volume and probability both before and after the modeled treatments. These results were then averaged for sub-basins in or neighboring the fuel reduction treatments (Table D.1). Based upon the modeling results, the modeled fuel reduction treatments did reduce both volume and probability of debris flows within the watershed. Post-fire debris flow volumes in the treated portions of the watershed are predicted to decrease by 12% and the probability that a debris flow would occur decreases by 27%.

Table D.1: Mean debris flow predictions for 313 sub-basins in or neighboring modeled fuel reduction treatments in the Mokelumne watershed.

	Avg Volume (m^3/ha)			Avg Probability in %		
Storm	Before treatments	Post treatments	Percent change	Before treatments	Post treatments	Percent change
2 year 2 hour	46	41	11%	0.059	0.044	25%
10 year 24 hour	187	163	13%	0.047	0.036	23%
25 year 1 hour	54	48	11%	0.14	0.090	34%
25 year 2 hour	64	57	11%	0.089	0.062	30%
25 year 24 hour	230	201	13%	0.049	0.037	24%
		mean	12%		mean	27%

Figure D.2: Debris flow modeling results for a 2 hour storm with a 25 year recurrence interval. Maps of predicted debris flow volumes (m^3/ha) a) before modeled fuel treatments and b) after modeled treatments. Probability maps of debris flow occurrence c) before modeled fuel treatments and d) after treatments.



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Disclaimer

This report is rich in data and analyses and may help support planning processes in the watershed. The data and analyses were primarily funded with public resources and are therefore available for others to use with appropriate referencing of the sources. This analysis is not intended to be a planning document.

The report includes a section on cultural heritage to acknowledge the inherent value of these resources, while also recognizing the difficulty of placing a monetary value on them. This work honors the value of Native American cultural or sacred sites, or disassociated collected or archived artifacts. This work does not intend to cause direct or indirect disturbance to any cultural resources.

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